Berkeley Lab DesignWorks

Single-Cell Core Position Sensor

User's Guide

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May 16, 2001

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1. Components

Figures 1a and 1b show the components that comprise the Single Cell Core Position Sensor. Figure 2 is a simplified flowchart showing how the components fit together.

Magnetic distance sensor

The magnetic distance sensor (SS12-1000AP2, Sensor Solutions Corp.) is a non-contact sensor that generates an analog voltage output proportional to the proximity and size of any ferrous metal within its sensing range. This sensor contains a permanent magnet, a magnetic flux density sensitive element, a voltage regulator, temperature compensation, an amplifier, and an adjustable subtraction circuit. Details of the sensor from the vendor are included in the appendix.

Sensor support fixture

The sensor support fixture is comprised of the following components:

- Sensor mount
- Sensor support body
- Sensor arm
- Mounting flange
- Turning wheel

The sensor support fixture's function is to guide and direct the sensor along the beam tube axis and rotate the sensor in the azimuthal direction. The magnetic distance sensor is mounted onto the sensor mount, which is in turn attached to the sensor arm. The sensor arm slides in the support body with two sleeve bearings at each end. A turning wheel is mounted to the other end of the sensor arm to manipulate the magnetic distance sensor. A mounting flange is attached to one side of the sensor support body to mount the Core Position Sensor to a DARHT-II accelerator cell.

Encoder

A bi-directional encoder (Model 260, Encoder Products Co.) is mounted on the sensor arm inside of the sensor support body to provide information on the angle of the magnetic distance sensor to the data acquisition system. The encoder has 1024 counts per revolution. Two guide shafts keep the encoder body from turning when the sensor arm is turned. Details of the encoder from the vendor are provided in the appendix.

Interconnect module (ICM)

An interconnect module (ICM-1900, Galil Motion Control) is used to connect the lead wires from the encoder and magnetic distance sensor to the the controller card in the computer. The

ICM-1900 accepts the 100-pin cable from the controller and provides screw terminals for quick and easy connection. The ICM-1900 is contained in a metal enclosure. Refer to Galil Motion Control DMC 1700/1800 Manual for information on ICM-1900.

Controller card

A PCI controller card (DMC-1800, Galil Motion Control) is used for data acquisition. The controller card sits in one of the PCI slots of the personal computer. The controller card reads the counts from the encoder and works in conjunction with the software to read the analog voltage output from the magnetic distance sensor at appropriate locations. The card also supplies the 12 volt power to the magnetic distance sensor (the power comes directly from the computer's power supply). Refer to Galil Motion Control DMC 1700/1800 Manual for information on the controller card.

Software

The software program (magsensor.exe) provides the following functions:

- Monitor the angle of the magnetic distance sensor
- Record the voltage reading from the magnetic distance sensor at 32 points on the circumference
- Record details of the measurement (cell number, core number, operator)
- Process the measurements (transform the data into the frequency domain with a fast Fourier transform)
- Output the location of the core relative to perfect alignment

The program is written in Microsoft Visual Basic with the ActiveX Toolkit from Galil Motion Control. A copy of the Visual Basic code is included in the appendix.

Computer

The computer is a Pentium class personal computer (Dell Optiplex GX 110). It has a Pentium III processor running at 866 MHz, 256 Mb cache, 64 Mb Non-ECC SDRAM, 10 Gb EIDE hard drive (7200 rpm), integrated Intel 3D graphics with Direct AGP and 4 Mb display cache, and is enclosed in a mini-tower chassis with a 200 watt power supply. The operating system on the computer is Microsoft Windows 98 Second Edition. The computer is supplied with a 15 inch Dell monitor. Please refer to the documentation provided with the computer for more details on the computer and monitor.

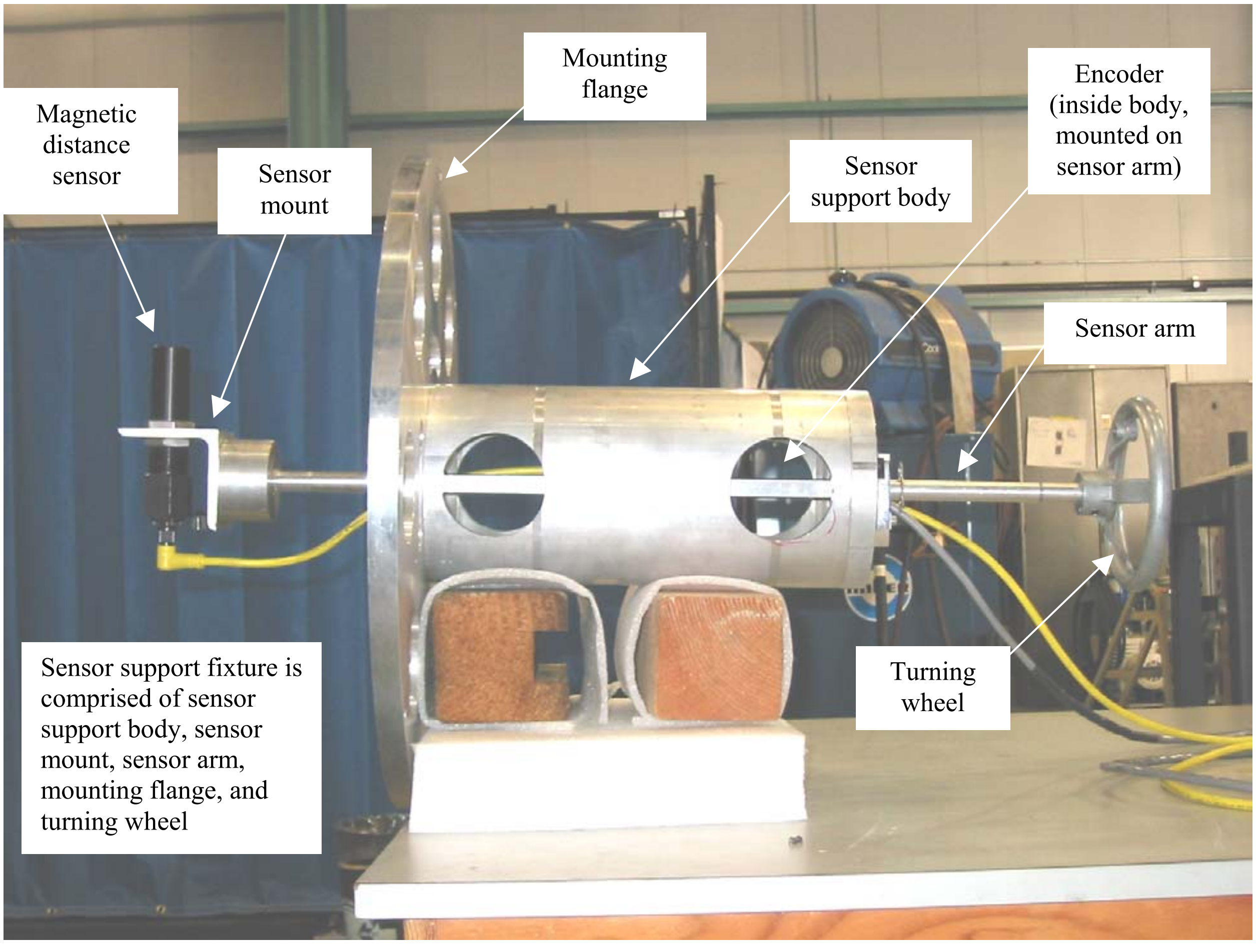


Figure 1a: Single Cell Core Position Sensor, sensor fixture components

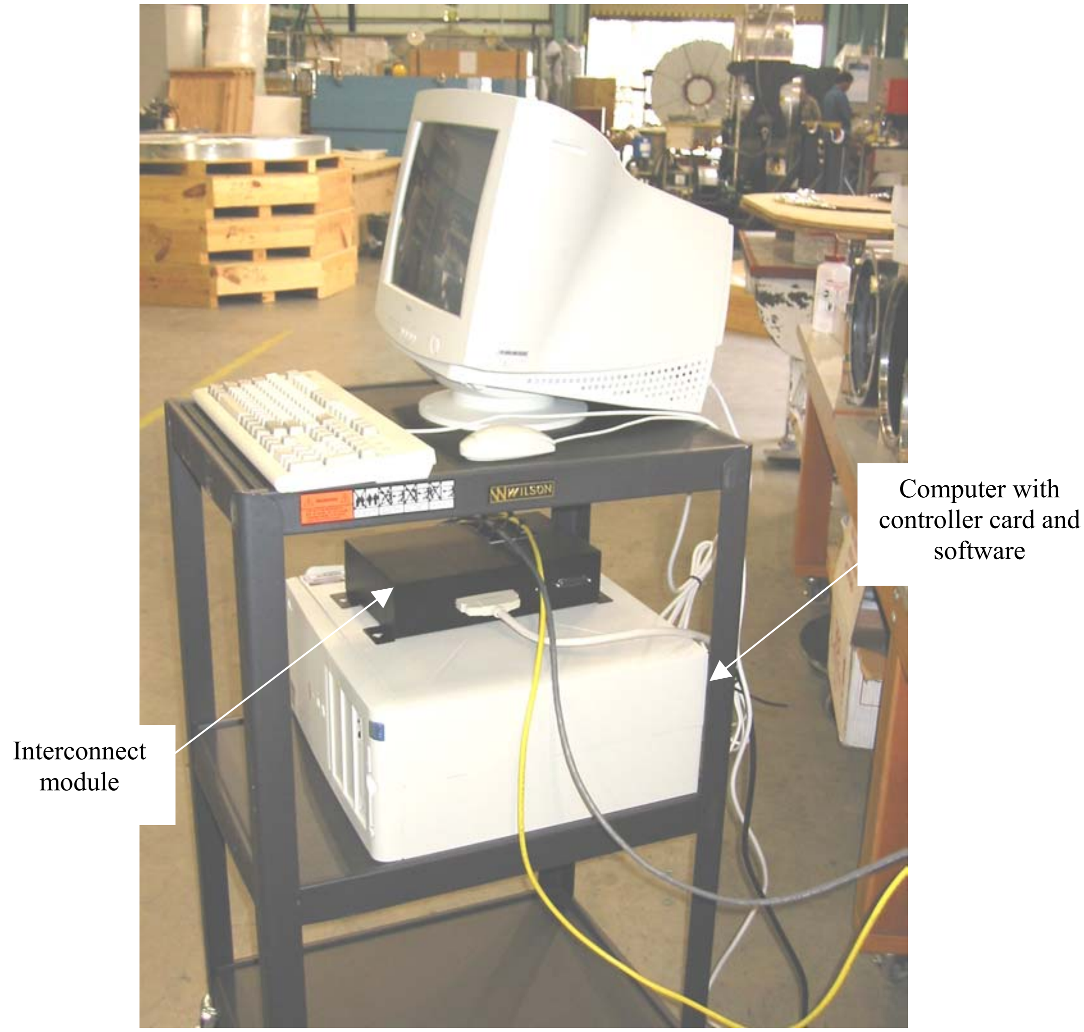


Figure 1b. Single Cell Core Position Sensor, data acquisition components

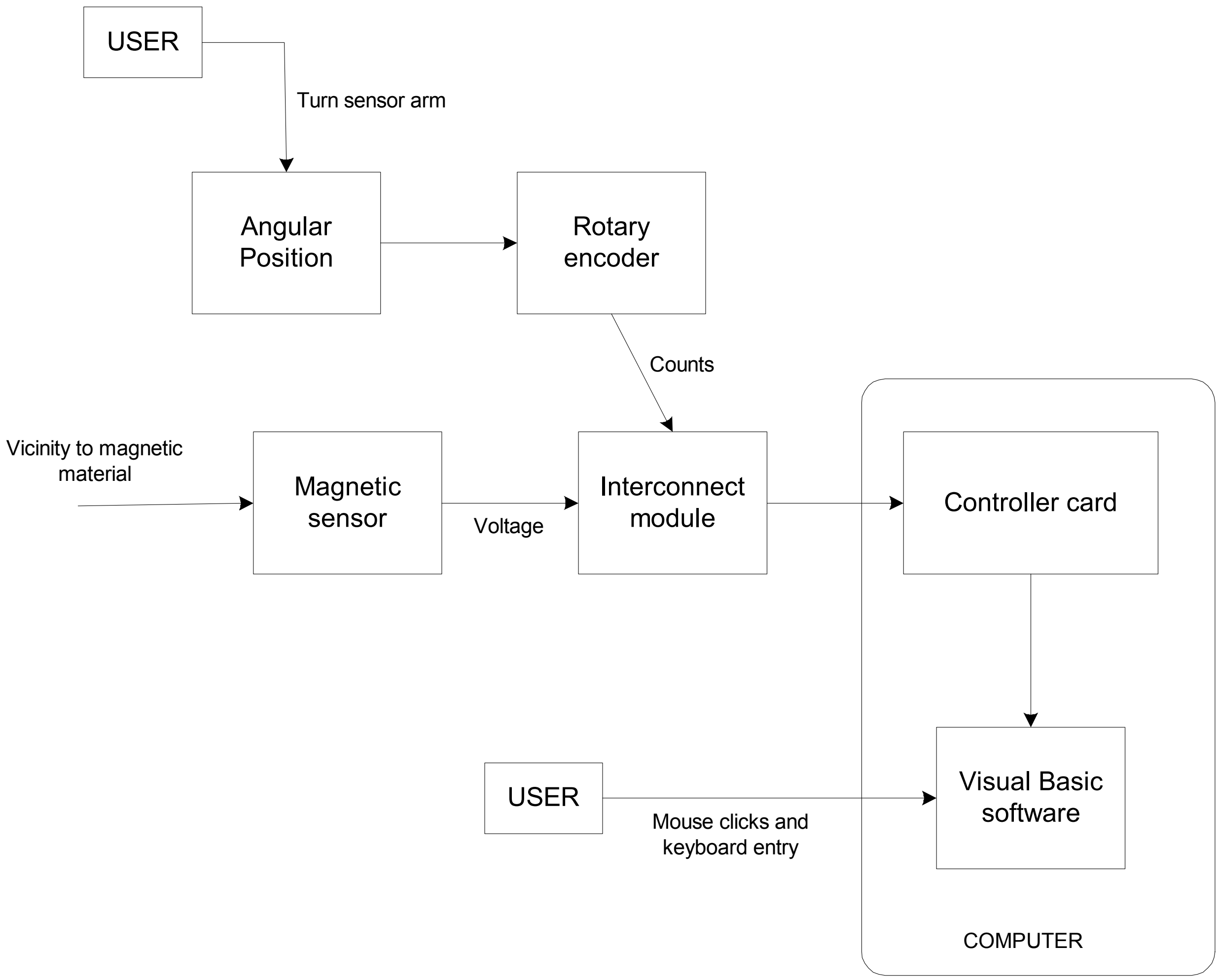


Figure 2. Flowchart of how components fit together.

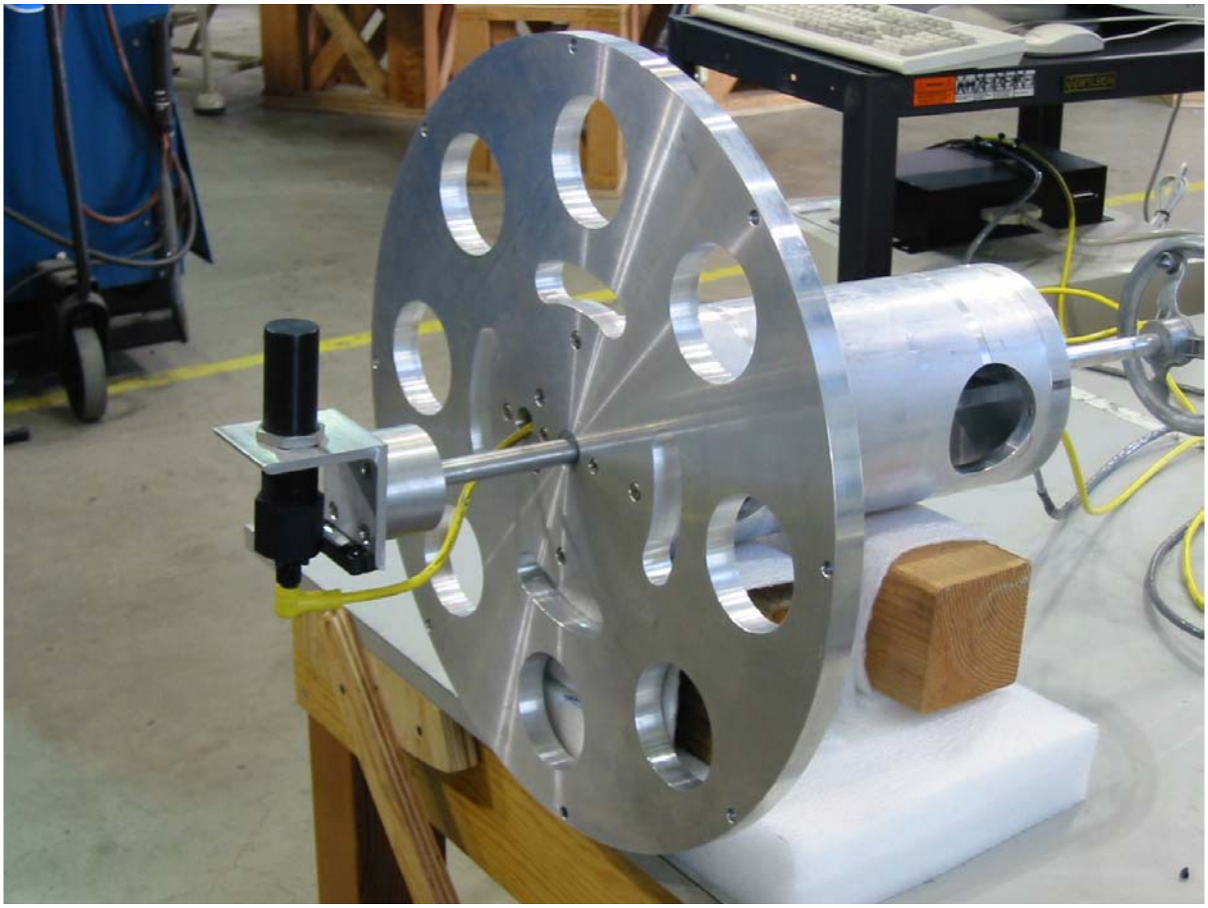


Figure 3. Image of Single-Cell Core Position Sensor showing end of mounting flange.

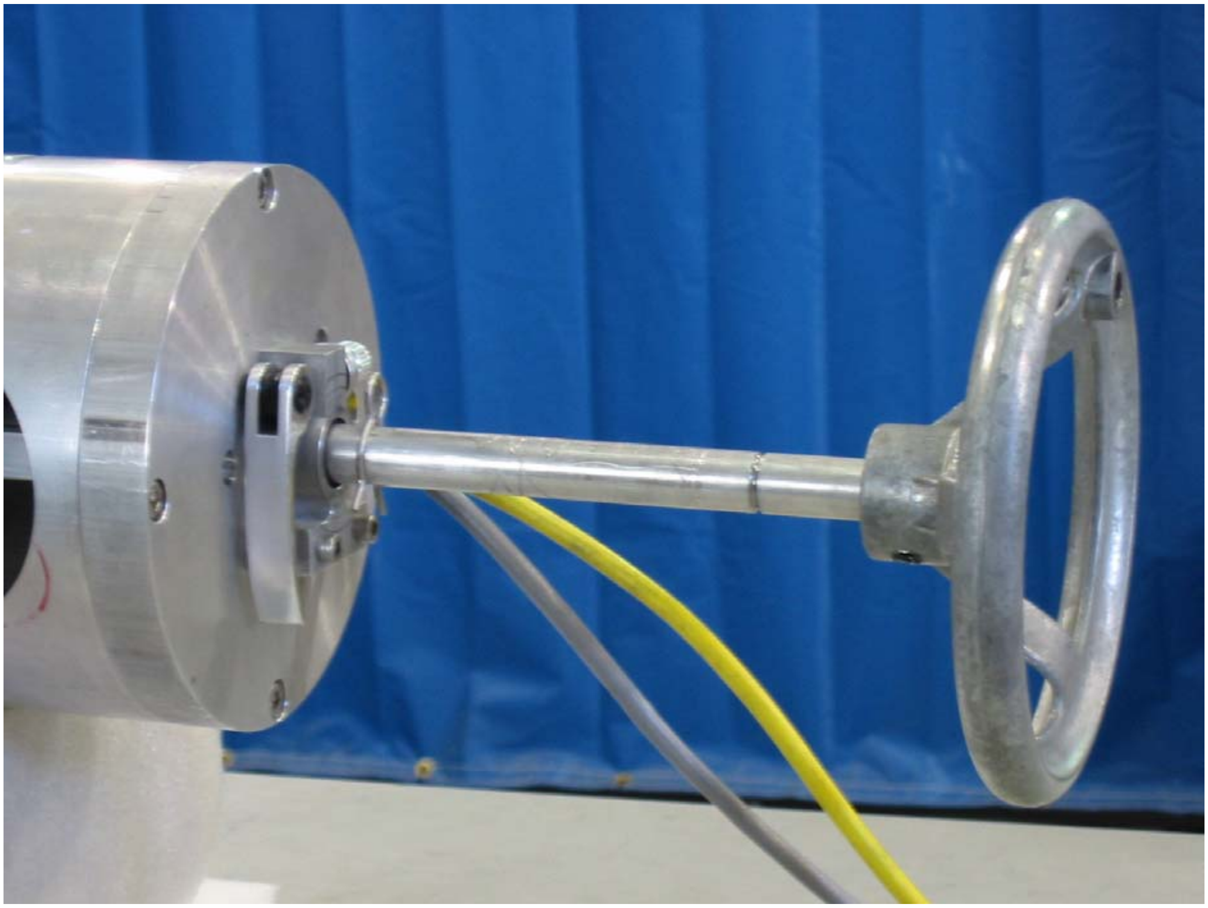


Figure 4. Core Position Sensor, turning wheel end.

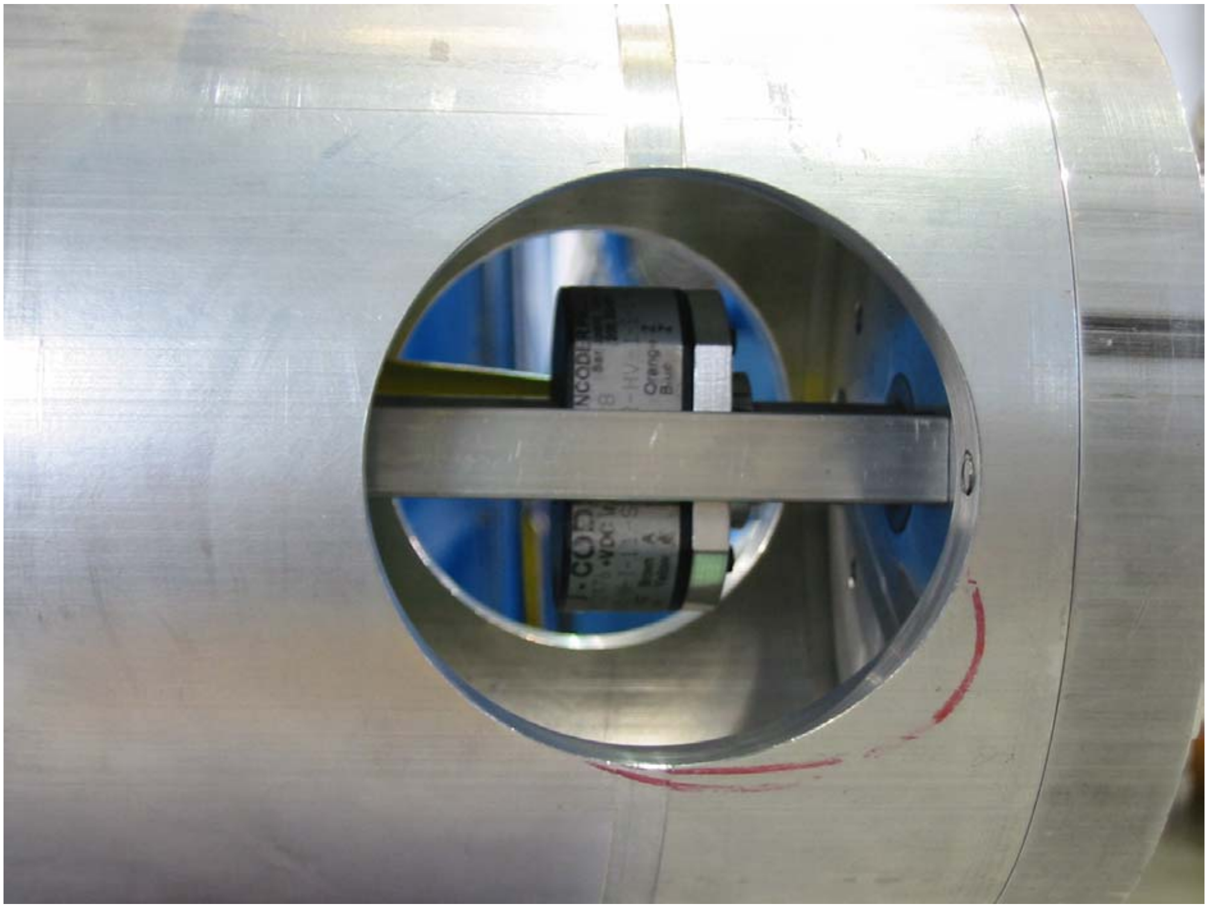


Figure 5. Side of Core Position Sensor showing encoder behind guide rod.

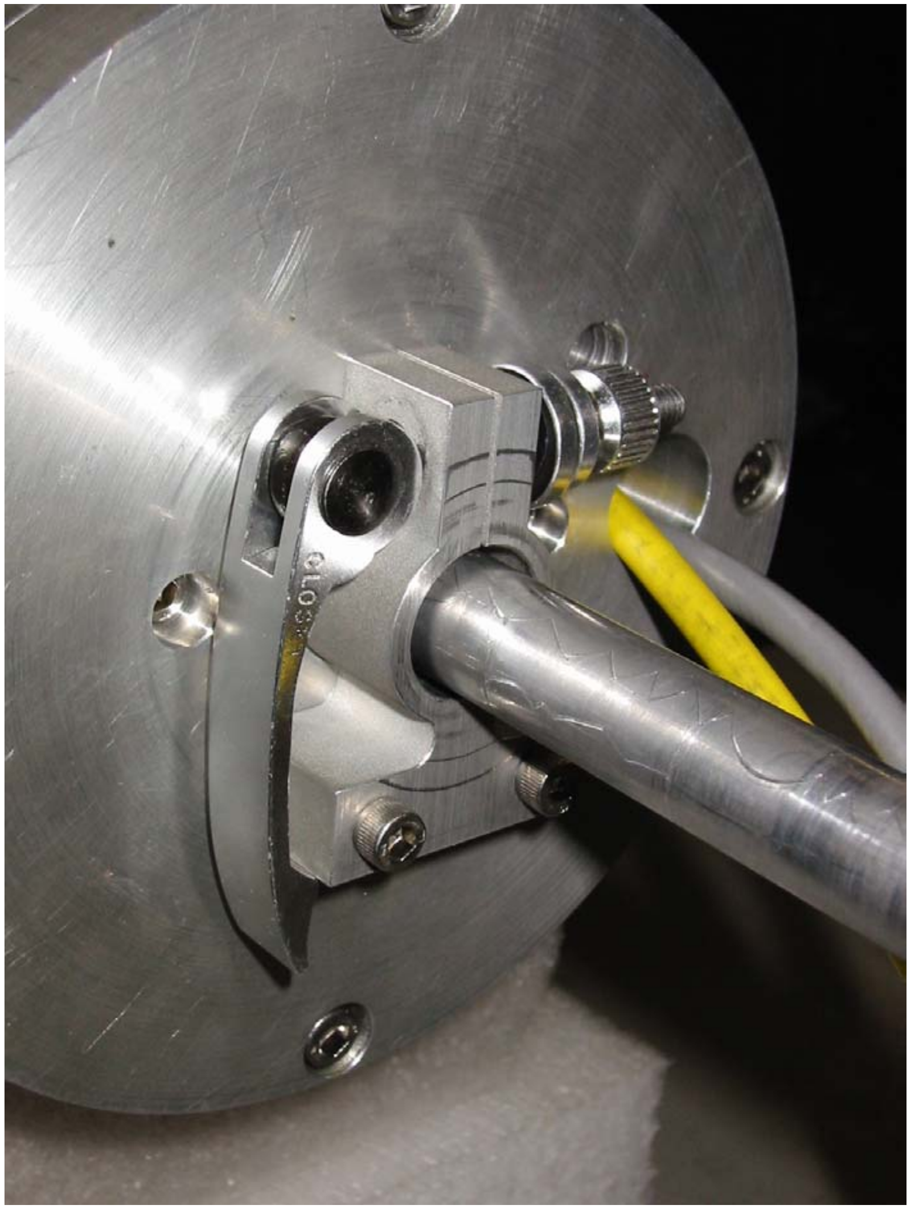


Figure 6. Core Position Sensor, showing locking mechanism at turning wheel end to lock the sensor arm.

2. How to Operate

Using the Single Cell Core Position Sensor requires following the steps outlined below:

1. Check that the leads from the encoder and magnetic distance sensor are connected to the ICM and the ICM cable is connected to the back of the computer.
2. Check that the magnetic distance sensor probe's tip is 4 inches from axis of revolution (6 inches for injector cells).
3. Clean the tip of the magnetic distance sensor probe using masking tape to remove all magnetic particles.
4. Install the sensor fixture to the beam tube end flange on the DARHT accelerator cell using 1/4 inch silver plated bolts (use the adapter flange and entended sensor bracket for measurement on injector cells). Take care to center the sensor fixture as best as possible.
5. Turn on the computer.
6. Start the Core Position Sensor program (located on Windows 98 Desktop). A window will open up titled "Magnetic Core Position Sensor". Figure 7 shows an image of the program screen and some of the screen components.
7. Align the magnetic distance sensor such that it points to top dead center (TDC). Use the bubble level, viewed through the slots on the mounting flange. A flashlight may be needed to provide adequate lighting to see the bubble level.
8. Click on the **Reset angle** button to set the angle to zero when the magnetic distance sensor is at TDC.
9. Click on the **Clear all entries** button to ensure a clean set of runs.
10. Enter the serial number and core number of the cell and core being measured in the section labeled **Step 2**. Measurements are conducted on one core at a time. Enter the operator's initials and any other notes in the text box titled **Operator**.
11. Click on the **Run 1** button in the section labeled **Step 3**.
12. Turn the wheel on the core position sensor fixture clockwise one full revolution. Turn at an even rate at a speed of approximately 20 seconds per revolution.
13. Click on the **Run 2** button in the section labeled **Step 3**.
14. Turn the wheel on the core position sensor fixture clockwise one full revolution. Turn at an even rate at a speed of approximately 20 seconds per revolution.
15. Click on the **Run 3** button in the section labeled **Step 3**.
16. Turn the wheel on the core position sensor fixture clockwise one full revolution. Turn at an even rate at a speed of approximately 20 seconds per revolution.
17. Click on the **Transform to Freq Domain** button.
18. Enter a filename to save the data in the textbox titled **Enter filename**.
19. Click on the **SAVE** button to save the data.
20. Click on the **Clear all entries** button to clear all data in the program and measure another core on the same cell.
21. When all measurements are completed, click on the **X** in the upper right corner of the window to close the program.
22. Un-install the core position sensor fixture from the cell.
23. Shut down Windows 98 and turn off the monitor.

System quirks you should know

Do not turn the wheel more than one full revolution in either direction

The encoder and magnetic distance sensor leads will wrap around the sensor arm if the wheel is turned more than 1 revolution in either clockwise or counterclockwise directions. After each run, it is best to turn the wheel counterclockwise back to zero degrees for subsequent runs.

Speed to turn the wheel

Turn the turning wheel at a speed of about 15 to 20 seconds per revolution.

After each of the Run buttons are pressed, the program monitors the probe angle and records the voltage output of the magnetic distance sensor when the probe is at the proper angle. It first monitors for zero degrees, then every 11.25 degrees until a full revolution is completed. If the user turns the wheel too fast, the computer may not keep up. In such a situation, the user may need to backtrack to pick up the reading that the computer may have missed. After the missed reading is picked up, the user should continue from the missed reading to the end of the revolution.

Lockout during runs

After each of the Run buttons are pressed, the background of the left panel turns red and the program is locked until the run is complete. The probe angle and sensor output listings DO NOT update during this lockout. The probe run must be completed in order for the program to return control to the user.

File saving

Files are saved only to one location. Saving files with the same name as an existing file will result in appending the new data to the end of the existing file. Files are saved in ASCII text format. All data is saved except for the approximate core position in millimeters. The **SAVE** button can only be used to save one file. Once a file is saved, the user should click on the **Clear all entries** button to continue.

Notes in operator entry

The program does not have a text entry box for notes. However, the user may enter short notes in the **Operator** text box after the operator's initials. Short notes are useful to distinguish between different runs on the same cell and core.

Cleaning sensor tip

It is very important to clean the magnetic distance sensor's tip. Stray magnetic shavings on the probe tip will result in inaccurate voltage output readings. An adhesive tape such as masking tape works well when cleaning the sensor tip.

Install fixture on center

Take care in installing the fixture on center. Since the probe measures the core position relative to its axis of revolution, the alignment between the core sensor fixture's axis and the beam tube axis is important in aligning the cores to the beam tube axis. Installation misalignments will directly result in inaccurate core position readings.

Clips to set axial position

The clips (shown near the locking mechanism in Figure 4) are used on the grooves to locate the magnetic distance sensor probe axially. Only two grooves exist; to measure core #2 (note that cores are numbered from DARHT upstream to downstream), fully retract the sensor arm and rotate the probe in the fully retracted position. To measure core #3, insert the clip in the groove near the middle of the sensor arm and push the sensor arm until the clip is against the locking mechanism jaws. To measure core #4, insert the clip in the groove closest to the turning wheel and push the sensor arm until the clip is against the locking mechanism jaws. Be sure to keep the clip against the locking mechanism jaws while the probe is rotating.

Scaling for distance interpretation

The scaling factors used in the program to convert the voltage amplitudes into core position are obtained from calibration runs on one cell. Three calibrations runs were performed, one each for cores #2, #3, and #4. The calibration runs were conducted on a dry cell in a horizontal position with all the cores sitting high 0.156 inch (3.96 mm). Further testing and calibration is needed to build confidence in the scaling factors.

Additional iterations may be used to bypass the need for the scaling factors. Taking a final measurement after moving the cores is useful to double-check that the first order sine and cosine terms in the frequency response is minimized. This ensures that the cores are aligned to the beam tube.

Beeping

The program beeps during each of the measurement runs. One beep occurs for each measurement taken. However, if the turning speed to higher than about 1 minute per revolution, the computer may skip some beeps. Fewer beeps is not an indication that measurements were skipped. The beeping is generated by the computer speaker and its volume may be somewhat low (it'll be hard to hear it in a noisy area).

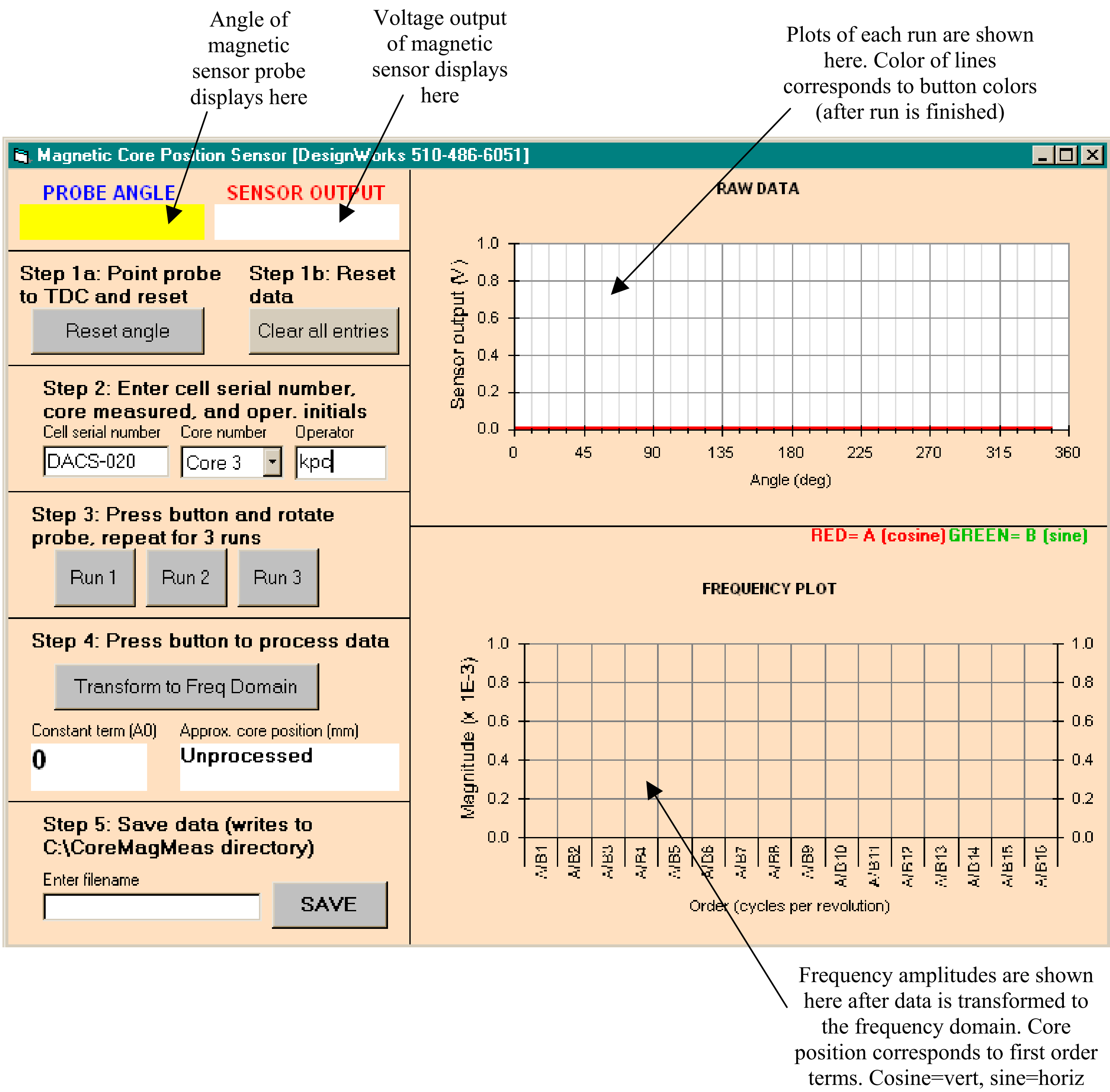


Figure 7. Image of screen for core position sensor program.

3. Some Technical Information

This section discusses some of the technical background behind the Core Position Sensor.

Sensor

The magnetic distance sensor is an off-the-shelf unit that provides a voltage output that varies with the amount and distance of magnetic material. The sensor voltage varies nonlinearly with distance when it is placed facing a large steel target (see vendor data in Appendix). In the distance of interest (1.8 to 2.2 inches from the core mandrel), the sensitivity of the sensor is approximately 1 volt per inch for a large steel target.

A 1k potentiometer is located a the back end of the magnetic distance sensor that can be adjusted to change the zero-target reading. The adjustment should not be below 0.4 volts when the sensor is not near any magnetic material.

Application Note #37 is included in the appendix for further details on the magnetic distance sensor.

FFT of data and interpretation

The software program performs a Fast Fourier Transform (FFT) of the averaged raw data from the three measurement runs. The FFT subroutine is adapted from "Numerical Recipes in Fortran 77". The FFT operation is important because the beam tube is slightly magnetic. By transforming the raw data into the frequency domain, we can isolate the contribution from the beam tube (generally higher order terms, since the non-uniformity in the beam tube magnetic response is due to an axial weld seam). The zero order term is simply the constant term of the average reading as the probe is rotated. The first order terms correspond to the position of the core mandrel. The first order cosine term corresponds to the vertical position and the first order sine term corresponds to the horizontal position. The second order terms correspond to ovalization of the core mandrel. The second order cosine term corresponds to ovalization in the 12-3-6-9 o'clock orientation and the sine term corresponds to ovalization in the 1:30-4:30-7:30-10:30 orientations. Monitoring the second and higher order terms is useful to ensure that unusual behavior is properly addressed.

The user should check to ensure that the higher order terms drop to zero as the order approaches 16. If the terms do not appear to drop to zero, aliasing may be occuring and more than 32 points may need to be measured around the circumference (i.e. the Nyquist frequency is too low).

The frequency plot shown on the program's graphical user interface is a single-sided FFT plot.

Note that large excursions from perfectly aligned conditions result in an increase in higher order terms due to the nonlinearity of the sensor output to distance. The Metglas cores are confined to only small excursions, therefore the nonlinearity is minor and its effect is probably negligible.

Contribution from each component

Figure 8 shows the response of the magnetic distance sensor when used to measure each of the components in the system independently. The locations of the inner diameters (ID) of each component are also shown in the figure. The solenoid component is not shown because it produced zero response from the magnetic distance sensor (since it is completely non-magnetic). Note that the sensitivity of the response with the sensor tip at the beam tube ID is as high for the beam tube as for the core. For the beam tube outer wall, the sensor is far enough away that its response is essentially flat regardless of how close the sensor comes to the beam tube. From the figure, we can select an appropriate distance for the sensor tip to be positioned. We want to have adequate sensitivity to the core (so that we can detect small off-center positions), but low sensitivity to the beam tube (so that its signal does not swamp the core's signal). A distance of 1 inch from the beam tube ID (4 inches from the bore axis) is selected as the nominal distance.

Calibration to length units

The system was calibrated to determine the scaling factors to convert amplitudes from the first order FFT results into core position units (mm). The scaling factors are obtained from calibration runs on one cell. Three calibrations runs were performed, one each for cores #2, #3, and #4. The calibration runs were conducted on a dry cell in a horizontal position with all the cores sitting high 0.156 inch (3.96 mm). The results of the calibration measurements are an average of 0.0147 volts per mm for the first order terms.

Further testing and calibration is needed to build confidence in the scaling factors.

Sensitivity of system

An initial measurement using the sytem indicate that the system can discern movements in the core position greater than 0.03 mm. Figure 9 shows a table of the difference in the FFT results for two measurements conducted on the same core and cell. The only difference between the two measurements is that the three bottom setscrews for the core were turned 1/16 of a turn. Note that only the first order terms (A1 and B1) changed more than 0.0004 volts (corresponding to 0.03 mm when we use the scaling factor of 0.0147). The A1 term corresponds to vertical movement and has a magnitude of 0.0027 (corresponding to 0.18 mm). The difference between the value of 0.18 mm as derived from the FFT results and the value of 0.1 mm that should result from a 1/16 turn of the setscrews can be attributed to the weak transfer function between the setscrew adjustments and movement of the Metglas core mandrel. Adjustment of the setscrews only corresponds roughly to movement of the core mandrel due to the "squishyness" of the cores.

Although a single intial measurement is not enough to definitively state the sensitivity of the system, we can comfortably say that the sensitivity is an order of magnitude lower than the initial measurement, or 0.3 mm of core movement.

Accuracy/repeatability

The accuracy and repeatability of the sytem is dependent on the following factors:

1. alignment during installation of core position fixture,
2. cleanliness of the magnetic distance sensor tip,
3. maintenance of consistent distance between the magnetic distance sensor tip to the beam tube ID,
4. axial positional accuracy,
5. magnetic distance sensor offset calibration, and
6. signal drift of the magnetic distance sensor.

With proper installation, the core position fixture can be aligned to within 0.5 mm of the beam tube axis. Proper procedures should be maintained to ensure the sensor tip does not have magnetic particles to disrupt the readings. Axial positional accuracy can also be maintained through consistent procedures during rotation of the probe.

Maintaining consistent distance between the probe tip and beam tube ID, having the same sensor offset calibration, and the signal drift of the sensor should not effect the overall results of the system. These items should result only in changing the constant term (A0) after the raw data is transformed into the frequency domain. The higher order terms should not be effected at all with a change in the sensor offset calibration or signal drift. If the sensor tip is placed closer to the beam tube, the contribution from the stainless steel beam tube is increased and the values from the higher order terms will be higher.

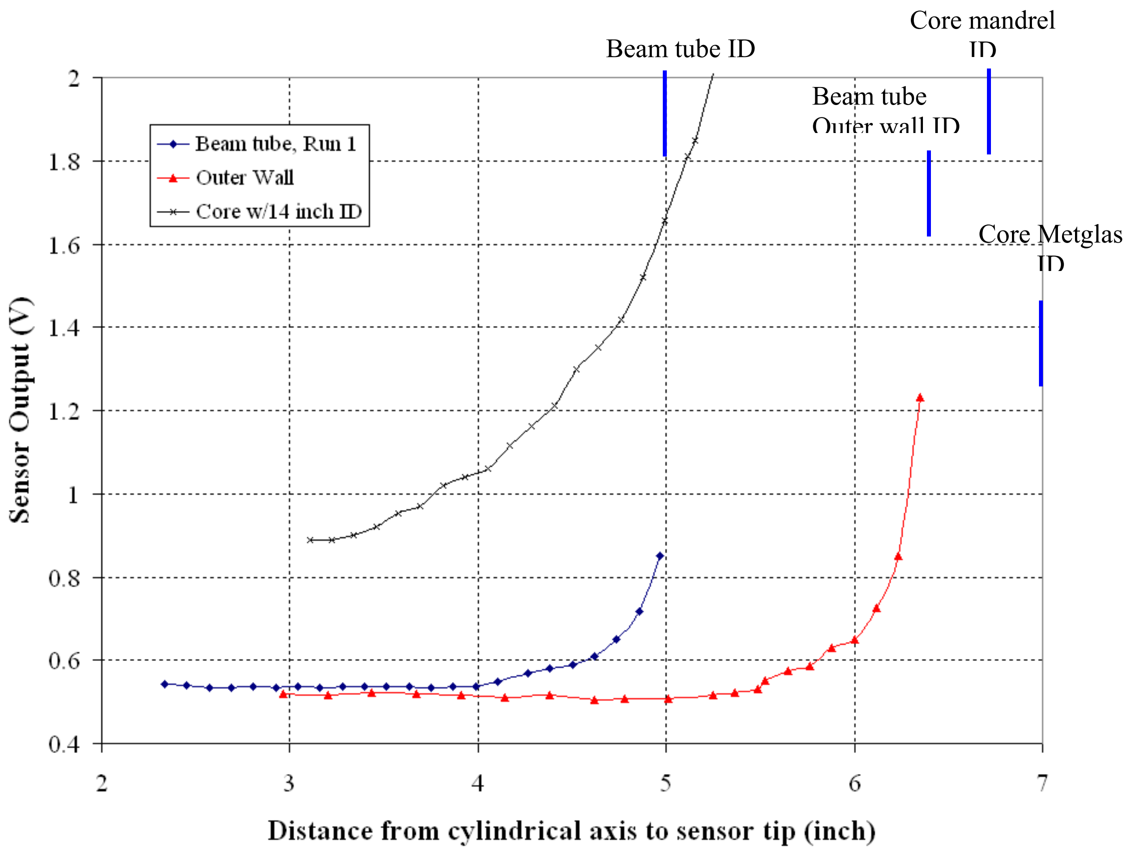


Figure 8. Plot of sensor output as a function of distance for each component between the sensor and the Metglas core

	FFT	
	Voltage amplitudes	
Order	A coeff	B coeff
0	0.0001	0.0000
1	-0.0027	0.0005
2	-0.0003	0.0000
3	0.0000	-0.0001
4	0.0004	0.0003
5	-0.0003	-0.0002
6	0.0002	0.0001
7	-0.0002	0.0002
8	0.0004	0.0004
9	0.0000	0.0002
10	0.0000	0.0001
11	0.0003	0.0000
12	-0.0004	-0.0002
13	0.0001	0.0000
14	0.0001	0.0000
15	0.0002	-0.0001

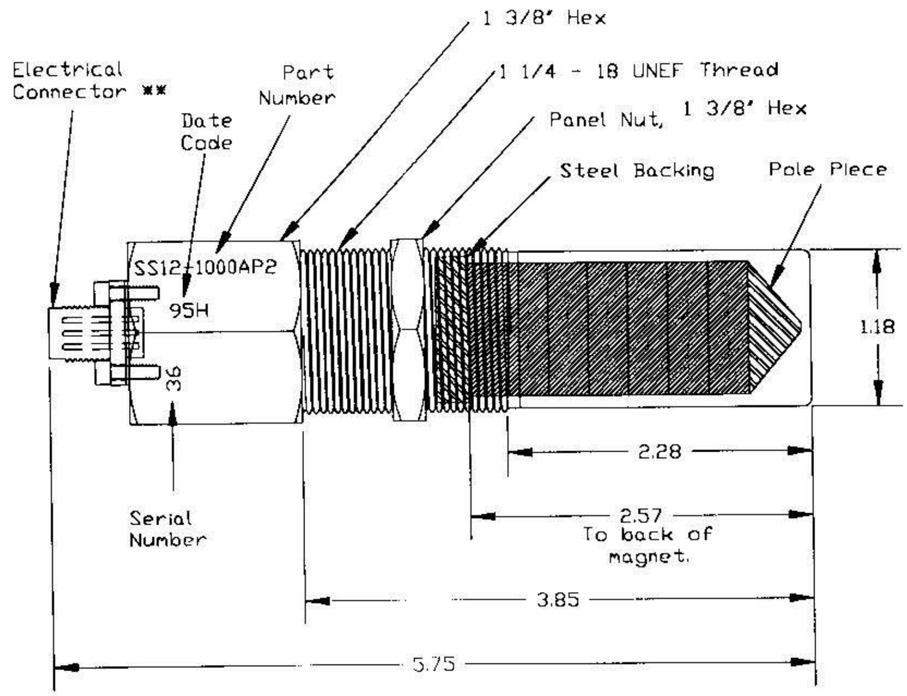
Figure 9. Table of voltage amplitude differences between measurements on core 4 (on the same cell) after core bottom setscrews adjusted 1/16 of a turn.

4. Appendix

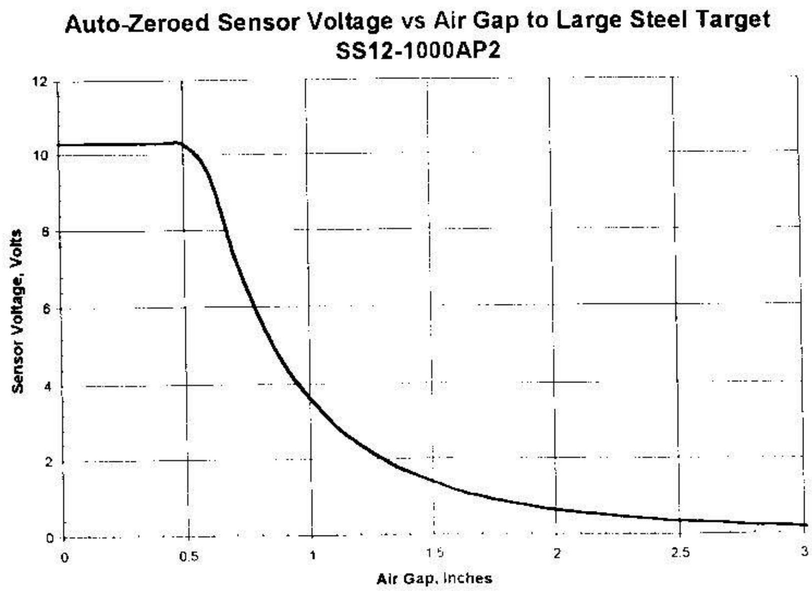
SS12-1000AP2 M-Drawing

SENSOR SOLUTIONS CORP. SOLID STATE FERROUS METAL ONLY DISTANCE SENSOR:

(970) 453-1850

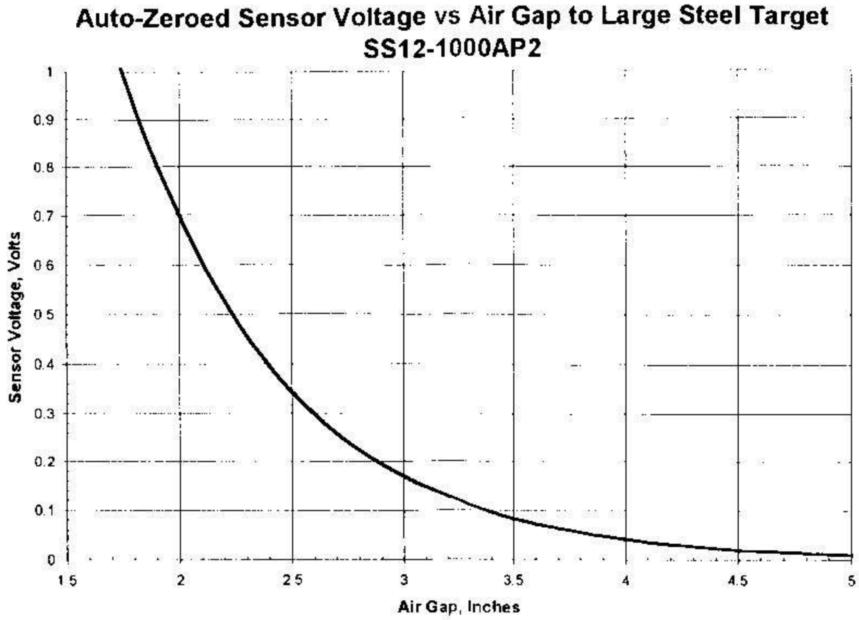


** Mates with Sensor Solutions 600-02 series cables.

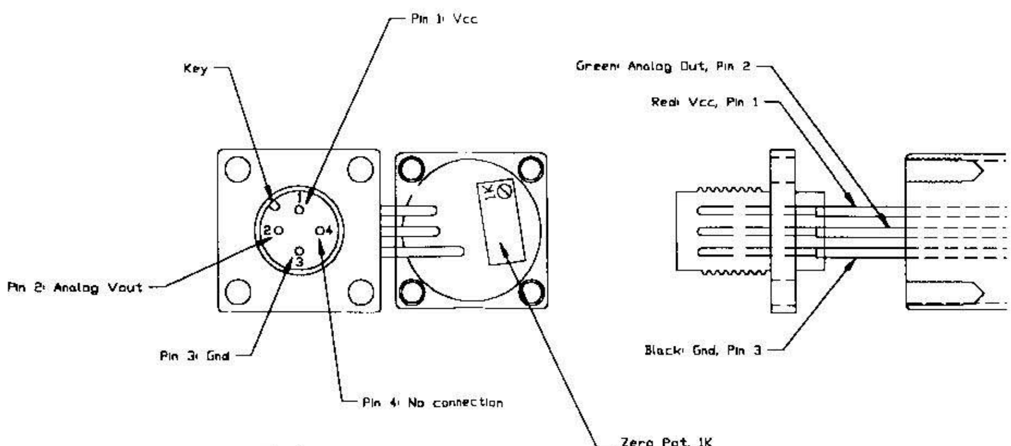


SENSOR OUTPUT, 0 TO 12 V SCALE
(Vcc = 12 V)

Rev 1/29/98



Your sensor is factory calibrated to produce 1.0 volts with no target present. You can change the offset of the sensor by adjusting the 1k potentiometer at the back of the sensor. This is a 12 turn pot, and the output will increase when it is turned clockwise. We recommend that you either leave the offset adjusted to 1 volt, or do not adjust it to below .4 volts to keep the output from saturating. Since ferrous metal in the sensor's mounting fixture can change this offset, check the output of the mounted sensor with no target present, and re-adjust it to 1.0 volt if necessary. It is possible to operate the sensor with the output at infinity adjusted to be in saturation (below 0.4 volts), but it is recommended that you discuss this with an applications engineer by calling (970) 453-1850.



CABLE COLOR CODE:

Pin	Color	Description
1	Brown	Vcc, 8 to 24 Volts DC
2	White	Analog Vout
3	Blue	Ground; connected to sensor housing
4	Black	Not connected to anything
	Shield	Terminated at the end of the cable